Naval Surface Warfare Center
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Coupled Dynamic Systems and Le Chatelier's Principle in Noise Control

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Investigation of coupling an adjunct dynamic system to an externally driven dynamic system - - a master dynamic system - - reveals that the response of the adjunct dynamic system affects the pre-coupled response of the master dynamic system. The responses, in the two dynamic systems when coupled, are estimated by the stored energies and , respectively. Since the adjunct dynamic system, prior to coupling was with zero stored energy, , the pre-coupled stored energy in the master dynamic system is expected to be reduced to when coupling is instituted; i.e., one expects . In this case a beneficial noise control of the master dynamic system would result from the coupling. It is argued that the change in the disposition of the stored energies as just described may not be the only change. The coupling may influence the external input power into the master dynamic system which may interfere with the expected noise control. Indeed, the coupling may influence the external input power such that the expected beneficial noise control may not materialize. An example of this kind of noise control reversal is cited.

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Abstract

Investigation of coupling an adjunct dynamic system to an externally driven dynamic system - - a master dynamic system - - reveals that the response of the adjunct dynamic system affects the pre-coupled response of the master dynamic system. The responses, in the two dynamic systems when coupled, are estimated by the stored energies (E_s) and (E_o), respectively. Since the adjunct dynamic system, prior to coupling was with zero (0) stored energy, $E_s^o = 0$, the pre-coupled stored energy (E_o^o) in the master dynamic system is expected to be reduced to (E_o) when coupling is instituted; i.e., one expects $E_o < E_o^o$. In this case a beneficial noise control of the master dynamic system would result from the coupling. It is argued that the change in the disposition of the stored energies as just described may not be the only change. The coupling may influence the external input power into the master dynamic system which may interfere with the expected noise control. Indeed, the coupling may influence the external input power such that the expected beneficial noise control may not materialize. An example of this kind of noise control reversal is cited.

Preface

This report is based on an accepted oral paper that was to be given at the 75th Anniversary Celebration, 147th Meeting of the Acoustical Society of America which was held at the Sheraton New York Hotel and Towers 24-28 May 2004. It was to be given, but was not. This misgiving occurred due to time constraint, mostly contributed by mismanagement of computer projections (power point) of preceding papers that got out of hand. The paper 2aSA5 was scheduled for delivery from 10:00 to 10:15. There was to be a scheduled Break from 10:15 to 10:30. The preceding paper 2aSA4 was still going strong at 10:18. The presenting authors of paper 2aSA5 refused to present the paper out-of-slot in the middle of the Break period. There is no particular blame to be singled out. There is, however, a recognition that unless the problems associated with the new forms of presentations are *nipped in the bud* early enough, chaos, in the scheduling of papers at the ASA Meetings, will reign supreme.

In this report it is intended to present the narrative on the left side and the viewgraphs on the right side. This form will enable the reader to follow the intended material in paper 2aSA5 as if he had attended the presentation. We hope that this will disseminate satisfactorily the information contained in the paper as if it were given.

The statement of Le Chatelier's Principle is rephrased for the noise control community on the first viewgraph, V1. Is the statement relevant to noise control engineering?

Note: Le Chatelier's Principle is a familiar dogma in physical chemistry. The extension of this Principle into noise control is in its infancy. Nonetheless, there are many examples in noise control engineering in which the essence of this Principle is validated. The awareness of this validity may help avoid pronouncements that are optimistic beyond the realm of reality.

G. Maidanik and K. J. Becker

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Naval Surface Warfare Center.

Work Supported by Contract to ONR.)

LE CHATELIER'S PRINCIPLE

IN NOISE CONTROL

Le Chatelier's Principle rephrased:

When a dynamic system is changed in order to induce a beneficial noise control, the modified dynamic system will act to mitigate the expected benefit.

V1

A statement of the example to be presented to illustrate
Le Chatelier's Principle, is stated in the second viewgraph, V2.

Note: This example lies within the area now termed *Structural Fuzzies*, so named by the initiator of this subject matter, Christian Soize of ONERA, France.

An Example:

A master dynamic system is coupled to a reverberant adjunct dynamic system in order to achieve a beneficial noise control. The master dynamic system experiences noise control that is less beneficial than that induced by an adjunct dynamic system that is effectively a sink (i.e., a non-reverberant adjunct dynamic system).

The master dynamic system pre-coupling is depicted atop the third viewgraph, V3. The master dynamic system is defined by the modal density $v_o(\omega)[\equiv v_o]$, the mass (M_o) and the loss factor $\eta_o(\omega)[\equiv \eta_o]$. The loss factor of $\eta_o(\omega)$ relates, by definition, the power $\Pi_o^o(\omega)[\equiv \Pi_o^o]$ dissipated to the stored energy $E_o^o(\omega)[\equiv E_o^o]$ in the uncoupled master dynamic system. On the other hand, by the *conservation of energy (power)* the power $\Pi_o^o(\omega)$ dissipated in this master dynamic system is equal to the external power input $\Pi_e^o(\omega)[\equiv \Pi_e^o]$. The relationship and the power equality may be expressed in the form

$$\Pi_o^o(\omega) = \eta_o(\omega)[\omega E_o^o(\omega)] = \Pi_e^o(\omega) \qquad ,(1)$$

where (ω) is the frequency. An adjunct dynamic system is coupled to the master dynamic system as shown. The adjunct dynamic system is defined by the modal density $v_s(\omega)[\equiv v_s]$, the mass (M_s) and the loss factor $\eta_s(\omega)[\equiv \eta_s]$. The loss factor $\eta_s(\omega)$ relates, by definition, the power $\Pi_s(\omega)[\equiv \Pi_s]$ dissipated to the stored energy $E_s(\omega)[\equiv E_s]$ in the adjunct dynamic system. On the other hand, by the conversation of energy (power) the power $\Pi_s(\omega)$ is equal to the net power $\Pi_s(\omega)[\equiv \Pi_s]$ that is transferred to the adjunct dynamic system. The relationship and the power equality may be expressed in the form

$$\Pi_s(\omega) = \eta_s(\omega)[\omega E_s(\omega)] = \Pi_s(\omega) \qquad .(2)$$

The net power $\Pi_s(\omega)$ may also be defined in the form

$$\Pi_s(\omega) = \eta_I(\omega)[\omega E_o(\omega)] \qquad ,(3)$$
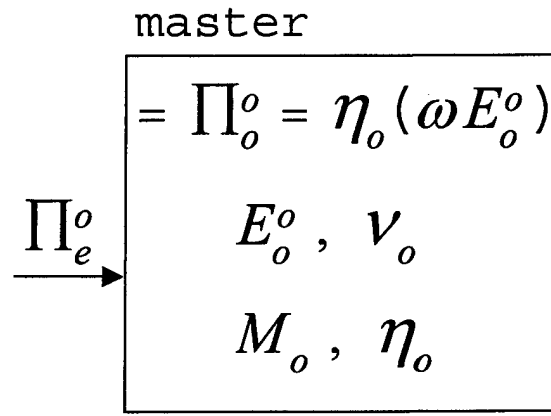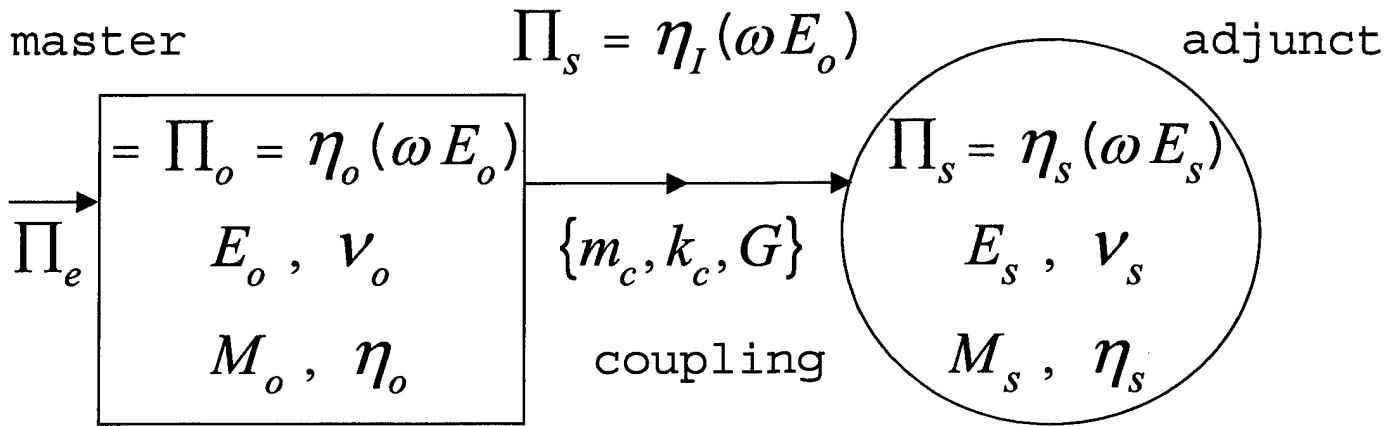
master

$$= \Pi_o^o = \eta_o(\omega E_o^o)$$

$$E_o^o \,,\ \nu_o$$

$$M_o \,,\ \eta_o$$

$$\Pi_e^o \longrightarrow$$

η_o loss factor of the master dynamic system

master $\qquad \Pi_s = \eta_I(\omega E_o) \qquad$ adjunct

$$= \Pi_o = \eta_o(\omega E_o)$$

$$E_o \,,\ \nu_o$$

$$M_o \,,\ \eta_o$$

$\Pi_e \longrightarrow$

$\{m_c, k_c, G\}$

coupling

$$\Pi_s = \eta_s(\omega E_s)$$

$$E_s \,,\ \nu_s$$

$$M_s \,,\ \eta_s$$

η_s loss factor of the adjunct dynamic system

$$\Pi_s = \eta_I\,(\omega E_o) = \eta_s\,(\omega E_s) \quad ;\quad Z_o^s = (E_s\,/\,E_o) \quad ,\ (\text{V3.1})$$

η_I induced loss factor of the master

dynamic system; induced by the coupling

Z_o^s global coupling strength: $(\eta_I\,/\,\eta_s) = Z_o^s$

. (V3.2)

where the loss factor $\eta_I(\omega)\,[\equiv \eta_I]$ is designated induced. As indicated in this third viewgraph, V3, considerations are focused on a master dynamic system that is externally driven; the adjunct dynamic system is not externally driven. A global coupling strength is defined, then, as the ratio of the stored energy in the adjunct dynamic system to the stored energy in the coupled master dynamic system. From Equations (2) and (3) one finds that the global coupling strength $Z_o^s(\omega)\,[\equiv Z_o^s]$ may be expressed in the form
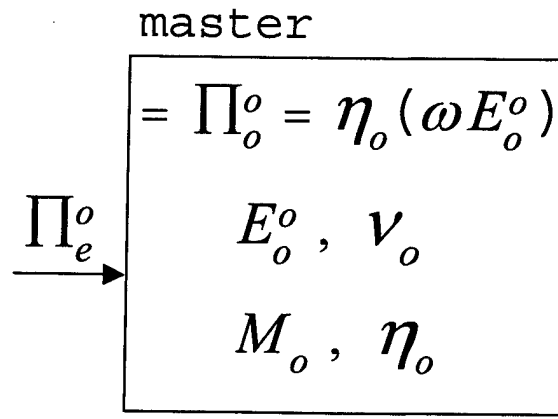
$$[E_s(\omega)/E_o(\omega)] = Z_o^s(\omega) = [\eta_I(\omega)/\eta_s(\omega)] \qquad \text{.(4)}$$

The ratio $Z_o^s(\omega)$ is the higher the stronger is the coupling and the higher is the ratio of the modal densities $[\nu_s(\omega)/\nu_o(\omega)]\,[\equiv \nu_s/\nu_o)]$.
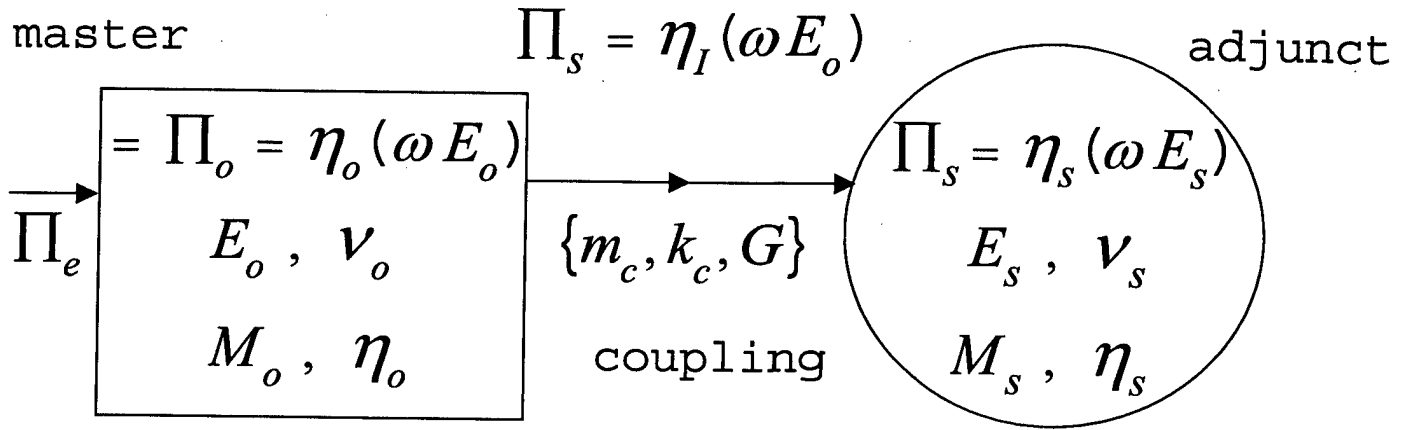
Note: In the statistical energy analysis (SEA) format

$$(E_s/E_o) = (\nu_s/\nu_o)(\varepsilon_s/\varepsilon_o) \;\; ; \;\; (\varepsilon_s/\varepsilon_o) = \eta_{os}(\eta_s + \eta_{os}) \qquad \text{,(5)}$$

where η_{os} is the coupling loss factor from the adjunct dynamic system to the master dynamic system and ε_o and ε_s are the stored modal energies in the master and in the adjunct dynamic systems, respectively. Clearly from Equation (5), if one wishes to render the global coupling strength high, the coupling loss factor (η_{os}) need to approach or exceed the loss factor (η_s). Then, the modal coupling strength $\varsigma_o^s = (\varepsilon_s/\varepsilon_o)$ approaches its maximum value of unity. In addition, to heighten the global coupling strength further, the ratio of the modal densities (ν_s/ν_o) needs be high. In that situation the adjunct dynamic system stores most of the stored energy in the combined dynamic system. If the loss factor (η_s) can be maintained simultaneously adequate to the task of gobbling the net power (Π_s), noise control benefit may be accrued. To examine the validity of this contention a more detailed analysis is required.

master

$$= \Pi_o^o = \eta_o(\omega E_o^o)$$

$$E_o^o \, , \, \nu_o$$

$$M_o \, , \, \eta_o$$

$$\Pi_e^o \longrightarrow$$

η_o loss factor of the master dynamic system

master $\qquad \Pi_s = \eta_I(\omega E_o) \qquad$ adjunct

$$= \Pi_o = \eta_o(\omega E_o)$$

$$E_o \, , \, \nu_o$$

$$M_o \, , \, \eta_o$$

$$\Pi_e \longrightarrow$$

$$\{m_c, k_c, G\}$$

coupling

$$\Pi_s = \eta_s(\omega E_s)$$

$$E_s \, , \, \nu_s$$

$$M_s \, , \, \eta_s$$

η_s loss factor of the adjunct dynamic system

$$\Pi_s = \eta_I \, (\omega E_o) = \eta_s \, (\omega E_s) \quad ; \quad Z_o^{\,s} = (E_s \, / \, E_o) \quad \text{, (V3.1)}$$

η_I induced loss factor of the master
dynamic system; induced by the coupling

$Z_o^{\,s}$ global coupling strength: $(\eta_I \, / \, \eta_s) = Z_o^{\,s}$

. (V3.2)

For this purpose a noise control parameter $\xi(\omega)[\equiv\xi]$ is defined in a way that a beneficial noise control is achieved if this parameter is small compared with unity; the smaller the parameter is, the more is the beneficial noise control. A noise control reversal occurs if the noise control parameter exceeds unity. Can a noise control reversal ever occur under the considerations here conducted?!
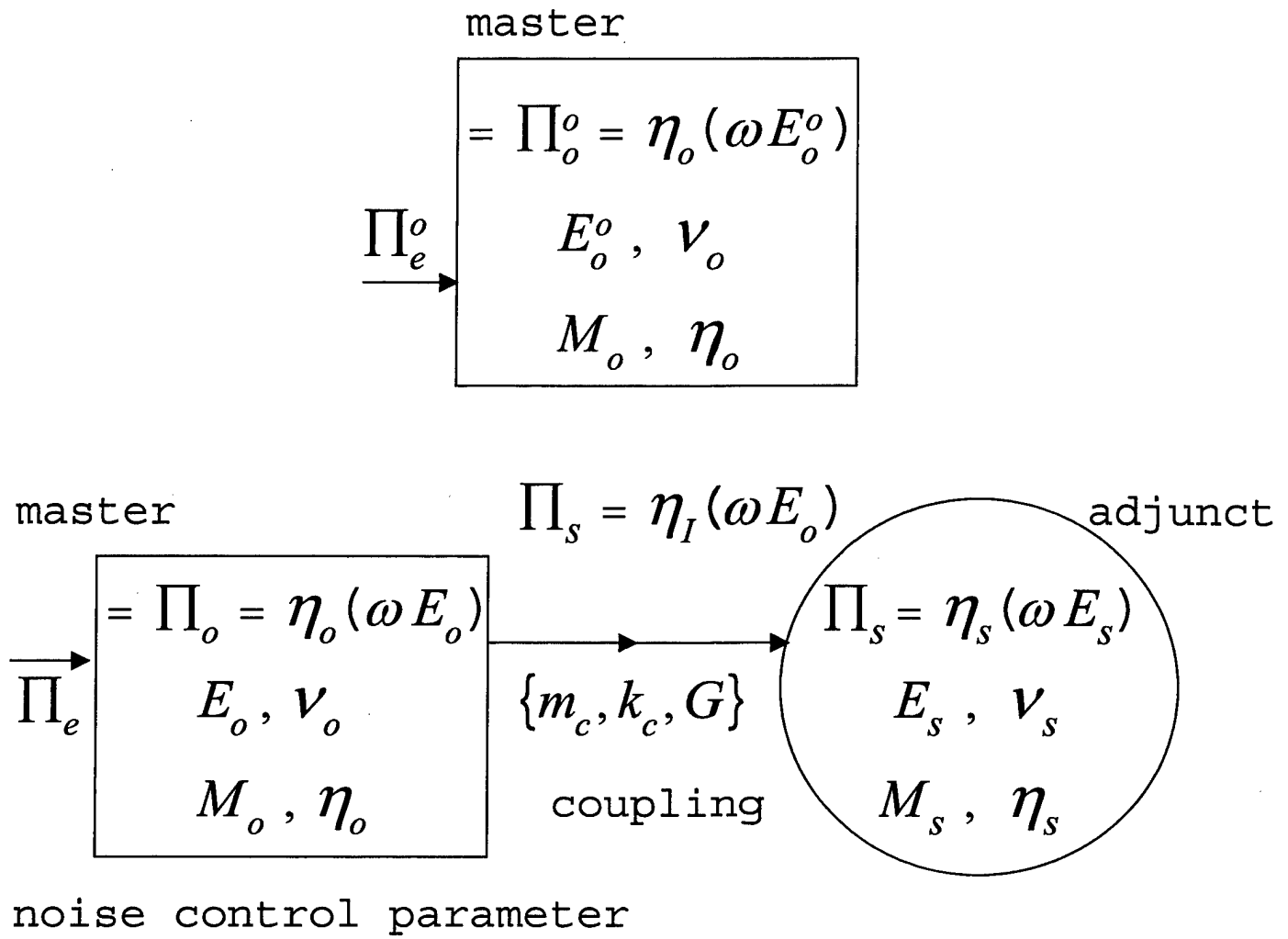
Note: In the statistical energy analysis (SEA) format

$$\xi_o = \eta_o(\eta_o + \eta_I)^{-1} \quad ; \quad \eta_I = (v_s/v_o)\eta_s\eta_{os}(\eta_s + \eta_{os})^{-1} \tag{6}$$

In SEA a consistency condition relates (η_{os}) to (η_{so}) in the form

$$(\eta_{os}v_s) = (\eta_{so}v_o) \tag{7}$$

where (η_{so}) is the coupling loss factor from the master dynamic system to the adjunct dynamic system. It is observed that if the coupling is weak; $\eta_s \gg \eta_{os}$, then the induced loss factor (η_I) is essentially independent of (η_s). On the other hand, if the coupling is strong; $\eta_s \ll \eta_{os}$, then (η_I) is essentially proportional to (η_s). Either way, (η_I) is proportional to the ratio of the modal densities (v_s/v_o). The higher this ratio is, the higher is the induced loss factor η_I. Thus a fact, nonetheless, if $\eta_I \gg \eta_o$, the beneficial contribution of ξ_o to the noise control parameter is significant.

master

$$= \Pi_o^o = \eta_o(\omega E_o^o)$$

$$E_o^o, \ \nu_o$$

$$M_o, \ \eta_o$$

$\Pi_e^o \longrightarrow$

master $\qquad$ $\Pi_s = \eta_I(\omega E_o)$ $\qquad$ adjunct

$$= \Pi_o = \eta_o(\omega E_o)$$

$$E_o, \ \nu_o$$

$$M_o, \ \eta_o$$

$\overrightarrow{\Pi_e} \longrightarrow$

$\Pi_s = \eta_s(\omega E_s)$

$$E_s, \ \nu_s$$

$$M_s, \ \eta_s$$

$\{m_c, k_c, G\}$

coupling

noise control parameter

$$\xi = [E_o / E_o^o] = \pi \ \xi_o \qquad\qquad , (V4.1)$$

external input power ratio $\pi = [\Pi_e / \Pi_e^o] \quad , (V4.2)$

loss factor ratio $\quad \xi_o = \eta_o [\eta_o + \eta_I]^{-1} \qquad , (V4.3)$

$$\eta_I = \eta_s Z_o^s \quad ; \quad \xi_o = [1 + (\eta_s / \eta_o) Z_o^s]^{-1} \qquad . (V4.4)$$

V4

In this fifth viewgraph, V5, an attempt is made to evaluate the ratio of the external power inputs $\pi(\omega)[\equiv \pi]$. This ratio is of the external power input $\prod_e(\omega)[\equiv \prod_e]$ into the coupled master dynamic system to the external power input $\prod_e^o(\omega)[\equiv \prod_e^o]$ in the absence of the coupling. Under the assumption that the mass of the adjunct dynamic system is small compared with that of the master dynamic system

$$\pi = \left(\prod_e / \prod_e^o\right) = \left(1 + Z_o^s\right) \tag{8}$$

[cf. Equations (V5.1)-(V5.7).]
Note: Employing Equations (6), (8) and (V4.4) one derives

$$\pi = 1 + \left(v_s / v_o\right)\eta_{os}\left(\eta_s + \eta_{os}\right)^{-1} > 1 \tag{9}$$

indicating that (π) exceeds unity, thereby, contributing contrarily to the factor (ξ_o) in the noise control parameter (ξ). In particular, for weak coupling; $\eta_{os} << \eta_s$, one derives

$$\pi = \pi_w \Rightarrow 1 + \left(v_s / v_o\right)\left(\eta_{os} / \eta_s\right) < 1 + \left(v_s / v_o\right) \tag{10}$$

whereas, for strong coupling; $\eta_{os} >> \eta_s$, one derives

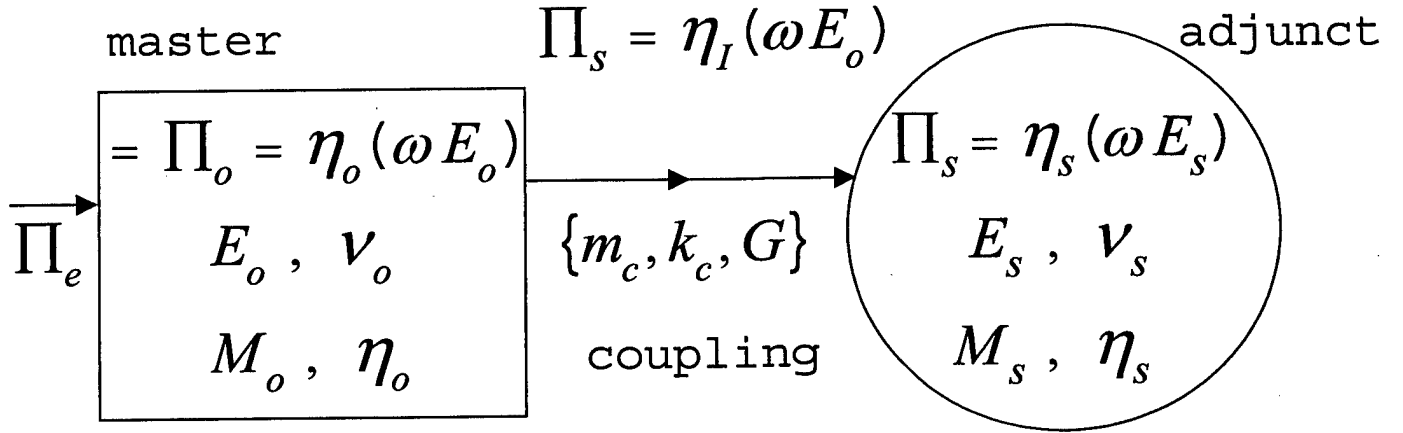$$\pi = \pi_s \Rightarrow 1 + \left(v_s / v_o\right) > \pi_w > 1 \tag{11}$$

Thus, strong coupling enhances (π) more than does weak coupling. Moreover, if (v_s / v_o) is high compared with unity, (π_s) may be similarly high. Beware, were (π) to be high, in excess of unity, it may negate effectively the beneficial noise control contributed by the factor (ξ_o) in the noise control parameter (ξ)!

master

$$\Pi_e^o \boxed{= \Pi_o^o = \eta_o(\omega E_o^o)}$$

inside box: E_o^o, ν_o

M_o, η_o

$$\Pi_e^o \cong S_f(\pi/2)[\nu_o / M_o] \qquad \text{(V5.1)}$$

$$\Pi_e \cong S_f(\pi/2)[\nu_o^s / M_o^s] \qquad \text{(V5.2)}$$

master $\qquad \Pi_s = \eta_I(\omega E_o) \qquad$ adjunct

$$\Pi_e \boxed{= \Pi_o = \eta_o(\omega E_o)}$$

inside box: E_o, ν_o

M_o, η_o

$\{m_c, k_c, G\}$

coupling

adjunct (circle): $\Pi_s = \eta_s(\omega E_s)$

E_s, ν_s

M_s, η_s

modified modal density

$$\nu_o^s = [\nu_o + \varsigma_o^s \, \nu_s] = \nu_o[1 + Z_o^s] \qquad \text{(V5.3)}$$

ς_o^s modal coupling strength: $Z_o^s = (\nu_s / \nu_o)\,\varsigma_o^s$ (V5.4)

assume: $(M_o / M_o^s) \cong 1 \qquad \text{(V5.5)}$

$$\Pi_e \cong S_f(\pi/2)[\nu_o / M_o][1 + Z_o^s] \qquad \text{(V5.6)}$$

$$\pi = [\Pi_e / \Pi_e^o] = [1 + Z_o^s] \qquad \text{(V5.7)}$$

The noise control parameter (ξ) is evaluated from Equations (V4.3), (V4.4) and (V5.7) to be

$$\xi = (E_o / E_o^o) = \pi \, \xi_o = (1 + Z_o^s) \, \eta_o (\eta_o + \eta_I)^{-1} \qquad \text{, (12a)}$$

or equivalently to be

$$\xi = (1 + Z_o^s) [1 + (\eta_s / \eta_o) Z_o^s]^{-1} \qquad \text{, (12b)}$$

The first example is illustrated assuming that the adjunct dynamic system is merely a sink. A sink is characterized such that it is incapable of storing energy; for an adjunct dynamic system that is a sink, (Z_o^s) is equal identically to zero; $Z_o^s = (E_s / E_o) \equiv 0$. For a sink then, the ratio (π), of the external power inputs, is equal to unity; $(\pi) = 1$, and, therefore, from Equation (12) one obtains

$$\xi \Rightarrow \xi_o = \eta_o (\eta_o + \eta_I)^{-1} \; ; \; \eta_I = (\eta_s \, Z_o^s) \qquad \text{. (13)}$$

Note: From Equations (6) and (13) one finds that in (SEA) the induced loss factor η_I may be equated in the form

$$\eta_I = (v_s / v_o) \eta_s \, \eta_{os} (\eta_s + \eta_{os})^{-1} \qquad \text{. (14a)}$$

It transpires that for a sink the loss factor (η_s) is such that the coupling is always weak; namely $\eta_s \gg \eta_{os}$. Then Equation (14) assumes the form

$$\eta_I \Rightarrow (v_s / v_o) \eta_{os} = \eta_{so} \qquad \text{, (15)}$$

where use is made of Equation (7). Thus, when the adjunct dynamic system is a sink, the loss factor of the coupled master dynamic system increases by the coupling loss factor (η_{so}). When coupling to the sink is implemented, the loss factor of the master dynamic system increases from that of (η_o) to $(\eta_o + \eta_{so})$.
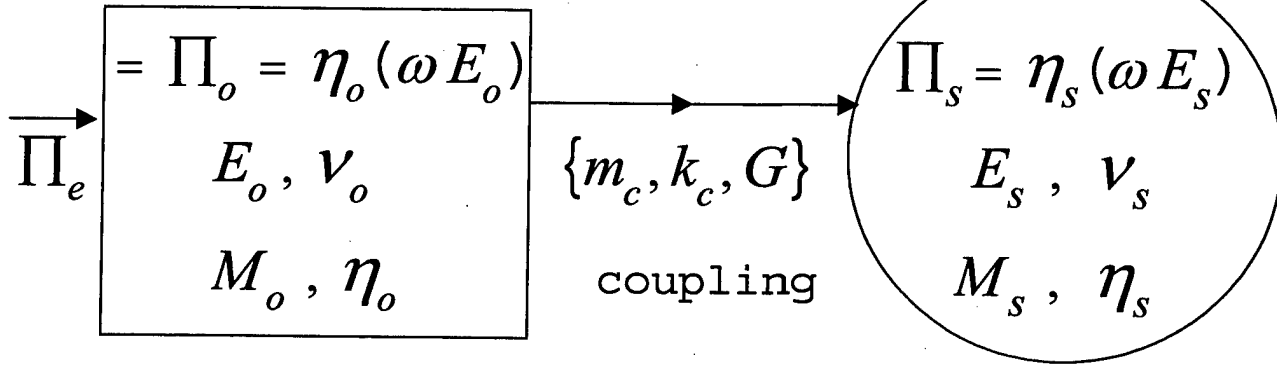
master

$$= \Pi_o^o = \eta_o(\omega E_o^o)$$

$$E_o^o , \quad \nu_o$$

$$M_o , \quad \eta_o$$

$\Pi_e^o \longrightarrow$

master

$$\Pi_s = \eta_I(\omega E_o)$$

adjunct

$$= \Pi_o = \eta_o(\omega E_o)$$

$$E_o , \quad \nu_o$$

$$M_o , \quad \eta_o$$

$\Pi_e \longrightarrow$

$\{m_c, k_c, G\}$

coupling

$$\Pi_s = \eta_s(\omega E_s)$$

$$E_s , \quad \nu_s$$

$$M_s , \quad \eta_s$$

noise control parameter

$$\xi = [E_o / E_o^o] = \pi \ \xi_o \Rightarrow [1 + Z_o^s][1 + (\eta_s / \eta_o)Z_o^s]^{-1}$$

Case 1.   merely a sink: $[E_s / E_o] = Z_o^s \Rightarrow 0$

$$\xi \Rightarrow \xi_o = [\eta_o][\eta_o + \eta_I]^{-1} \quad ; \qquad \pi = 1$$

loss factor in master increases by the induced loss

factor: $\eta_I = \eta_s Z_o^s$

V6

In this seventh viewgraph, V7, two cases are investigated. In both these cases; case 2 and case 3, the global coupling strength is assumed to be in excess of unity; $Z_o^s \gg 1$. In case 2 the loss factor (η_s) in the adjunct dynamic system is assumed to exceed the loss factor (η_o) in the master dynamic system; $\eta_s > \eta_o$. The noise control parameter is beneficial to the degree that (η_s) exceeds (η_o). This is a reasonable result. It is of interest to consider that were one to assume (falsely) that the ratio (π) of the external power inputs is unity, the noise control benefit would be greatly (and falsely) enhanced. In case 3 the loss factor (η_s) in the adjunct dynamic system is assumed to be less than the loss factor (η_o) in the master dynamic system; $\eta_s < \eta_o$. The noise control parameter shows deficient result - - a noise control reversal! Again, it is of interest to consider that were one to assume (falsely) that the ratio (π) of the external power inputs is unity, the noise control benefit would be greatly (and falsely) recovered.

A corollary to cases 2 and 3 is afforded by equating (η_s) to (η_o). Under this condition the noise control parameter is neutral, registering a value of unity. Indeed, in this case the increase in the external power input to the coupled master dynamic system; i.e., (Π_e), as compared with that to the isolated master dynamic system; i.e., (Π_e^o), balances the increase in the loss factor of the coupled master dynamic system; i.e., $(\eta_o + \eta_I)$, as compared with that of the isolated master dynamic system; (η_o). This balance renders $\xi \Rightarrow 1$. Once again, were one to assume (falsely) that the ratio (π) of the external power inputs is unity, the noise control benefit would be greatly (and falsely) enhanced.

noise control parameter

$$\xi = [E_o / E_o^o] = \pi \ \xi_o \Rightarrow [1 + Z_o^s][1 + (\eta_s / \eta_o) Z_o^s]^{-1}$$

in subsequent cases: $[E_s / E_o] = Z_o^s \gg 1$

Case 2. $[\eta_s / \eta_o] > 1$ $\qquad \xi \Rightarrow [\eta_o / \eta_s] < 1$

Were $\pi \Rightarrow 1$ then $\xi \Rightarrow \eta_o [1 + (\eta_o / \eta_s) Z_o^s]^{-1} \ll 1$

Case 3. $[\eta_s / \eta_o] < 1$, $\qquad [(\eta_s / \eta_o) Z_o^s] \gg 1$

$\xi \Rightarrow [\eta_o / \eta_s] > 1$ a noise control *reversal*.

Were $\pi \Rightarrow 1$ then $\xi \Rightarrow \eta_o [1 + (\eta_s / \eta_o) Z_o^s]^{-1} \ll 1$

A corollary to cases 2 and 3: $\eta_o = \eta_s$

$\xi \Rightarrow 1$; $\pi \Rightarrow [1 + Z_o^s] > 1$; $\xi_o \Rightarrow [1 + Z_o^s]^{-1} < 1$

Were $\pi \Rightarrow 1$ then $\xi \Rightarrow [1 + Z_o^s]^{-1} \ll 1$

V7

It is, then, suggested: Noise control engineers beware, Le Chatelier's Principle is there to undermine your predictions were you not careful to recognize that Principle's existence.

Note: If one couples an adjunct dynamic system on to a master in order to achieve noise control, one needs to ensure that most of the stored energy (E) ; $E = (E_o + E_s)$, in the combined dynamic system (master + adjunct) resides in the adjunct dynamic system; i.e., $(E_s / E_o) \gg 1$. However, this condition is not enough, one must ensure also that the adjunct dynamic system has a loss factor (η_s) high enough to participate effectively in the dissipation of the external power input $(\prod_e)$. This external power input exceeds the external power input $(\prod_e^o)$ that is imparted to the master dynamic system in the absence of the coupling. The effective dissipation of $(\prod_e)$ is thus imperative. The eighth viewgraph, V8, is introduced, for the purpose of evaluating this statement.

noise control parameter

$$\xi = [E_o \ / \ E_o^o] = \pi \ \xi_o \Rightarrow [1 + Z_o^s][1 + (\eta_s \ / \ \eta_o) Z_o^s]^{-1}$$

in subsequent cases: $[E_s \ / \ E_o] = Z_o^s \gg 1$

Case 2. $[\eta_s \ / \ \eta_o] > 1 \qquad \xi \Rightarrow [\eta_o \ / \ \eta_s] < 1$

Were $\pi \Rightarrow 1$ then $\xi \Rightarrow \eta_o[1 + (\eta_o \ / \ \eta_s) Z_o^s]^{-1} \ll 1$

Case 3. $[\eta_s \ / \eta_o] < 1$, $[(\eta_s \ / \eta_o) Z_o^s] \gg 1$

$\xi \Rightarrow [\eta_o \ / \ \eta_s] > 1$ a noise control *reversal*.

Were $\pi \Rightarrow 1$ then $\xi \Rightarrow \eta_o[1 + (\eta_s \ / \ \eta_o) Z_o^s]^{-1} \ll 1$

A corollary to cases 2 and 3: $\eta_o = \eta_s$

$\xi \Rightarrow 1 \ ; \quad \pi \Rightarrow [1 + Z_o^s] > 1 \ ; \quad \xi_o \Rightarrow [1 + Z_o^s]^{-1} < 1$

Were $\pi \Rightarrow 1$ then $\xi \Rightarrow [1 + Z_o^s]^{-1} \ll 1$

V7

From Equations (V4.1) and (V4.3), (V5.7) and (V8.1) the ratio of the initial loss factor (η_o) to the effective loss factor (η_e) of the dynamic system (master + adjunct) may be established in the form

$$(\eta_o/\eta_e) = \xi = [1 + (\eta_I/\eta_o)][1 + (\eta_I/\eta_s)]^{-1} \qquad .(16)$$

It follows that if (η_o) is less than (η_s) then

$$\xi < 1 \quad ; \quad \eta_o < \eta_s \qquad ,(17a)$$

and if (η_o) exceeds (η_s) then

$$\xi > 1 \quad ; \quad \eta_o > \eta_s \qquad ,(17b)$$

which reemphasize Cases 2 and 3, respectively, as presented in the preceding viewgraph, V7. Moreover, if $\eta_o = \eta_s$ then

$$\xi = 1 \quad ; \quad \eta_o = \eta_s \qquad ,(18)$$

The validity of Equations (17) and (18) are independent of the value of the induced loss factor η_I. In (SEA) the induced loss factor may be cast in the form

$$\eta_I = (\eta_{so})[\eta_s(\eta_{os} + \eta_s)]^{-1} \leq \eta_{so} \qquad .(19)$$

The equality occurs only if the coupling is weak; i.e., only if $\eta_{os} \ll \eta_s$. Weak coupling characterizes the case, for example, when the adjunct dynamic system is a sink. [cf. Equation (15) and the case; Case 1, depicted in the sixth viewgraph, V6.]

master

$$\Pi_e \mid = \eta_v(\omega E_o)$$
$$E_o, \ \nu_o$$
$$M_o, \ \eta_v$$

master + adjunct

$$\Pi_e \mid = \eta_e(\omega E)$$
$$E = (E_o + E_s), \ \nu_o^s$$
$$M_o^s, \ \eta_e$$

$$\eta_v(\omega E_o) = \eta_e(\omega E) \quad ; \quad \eta_v = \eta_o + \eta_I \quad ; \quad \eta_v = \eta_e(1 + Z_o^s)$$

, (V8.1)

η_v the virtual loss factor of the coupled master dynamic system

η_e the effective loss factor of the coupled dynamic system (master + adjunct)

noise control parameter

$$\xi = [E_o / E_o^o] = \pi \ \xi_o$$

$$\Rightarrow [1 + Z_o^s][\eta_o / \eta_v] \Rightarrow [\eta_o / \eta_e] \qquad \text{. (V8.2)}$$

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